Mixed Layer Drift Revealed by Satellite Data

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Highlight: For the first time we are able to derive ocean currents using the wavelet algorithm for feature tracking from two different sensors (MODIS and SeaWiFS) on different satellites. Satellite ocean color data provide an important insight to the marine biosphere because of their capability to quantify certain fundamental properties (such as phytoplankton pigment concentration, marine primary production, etc.) on a global basis. The mixed layer drift can be derived because the ocean color signal bears information from a much larger depth (10 to 30 meters) as compared with the sea surface temperature data. Although the drifter data are very limited in the study area, the comparison shows a general agreement between drifter data and satellite tracking results, especially for the cases near the Gulf Stream boundary.

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For the first time we are able to derive ocean currents using the wavelet algorithm for feature tracking from two different sensors on different satellites. Satellite ocean color data provide an important insight to the marine biosphere because of their capability to quantify certain fundamental properties (such as phytoplankton pigment concentration, marine primary production, etc.) on a global basis. The mixed layer drift can be derived because the ocean color signal bears information from a much larger depth (10 to 30 meters) as compared with the sea surface temperature data.

At present, there are two major global ocean color sensors in orbit. After the launch of the Sea-viewing Wide Field-of-View Scanner (SeaWiFS) onboard the Orbview 2 satellite in August 1997 [McClain et al., 1998], the Moderate Resolution Imaging Spectroradiometer (MODIS) was launched aboard the Terra (EOS AM-1) satellite on December 18, 1999. MODIS is viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths including those analogous to SeaWiFS for ocean color. These data will improve our understanding of global dynamics and processes on the land, in the oceans, and in the lower atmosphere. MODIS is playing a crucial role in the development of global Earth system models to assist policy makers in making decisions for environment protection [Esaias et al., 1998]. A high degree of overlap between MODIS and SeaWiFS exists globally on a daily basis. With more than one ocean color sensor in orbit, new data products such as mixed layer drift can be derived when two satellite tracks overlap within a short time without cloud coverage.

In this note, we demonstrate how the chlorophyll-a concentration data derived from both MODIS and SeaWiFS can be used to derive mixed layer drift. The data from MODIS and SeaWiFS (Figure 1) were collected on May 8, 2000 at 15:45 and 16:52 GMT, respectively, off the East Coast of the US. The major features of the Gulf Stream boundary and a large cold-core eddy south of the Gulf Stream can be clearly identified. To validate the results, several drifters' data are used to compare with the satellite derived flow field. The comparison shows general agreement and consistent pattern.

Wavelet Analysis of Satellite Images

A two-dimensional wavelet transform is a highly efficient band pass-filter. The two-dimensional Gaussian wavelet (often referred to as a "Mexican hat" wavelet) has been applied to satellite images to separate processes at various scales including relative phase/location information for coastal monitoring applications [Liu et al., 1997a] and for ice edge and ice floe tracking [Liu et al., 1997b]. The wavelet transform of a satellite image for small-scale features can be used with transforms of various scales to separate texture or features, for near real-time "quick look" analyses of satellite data for feature detection, and for data reduction using a binary image. Wavelet analysis of NSCAT (NASA Scatterometer) backscatter and SSM/I (Special Sensor Microwave/Imager) radiation data can also be used to obtain daily sea-ice drift information for both the northern and southern polar regions [Liu et al., 1998; 1999; Zhao et al., 1998; Liu and Cavalieri, 1998]. Overall, the comparison of NSCAT and SSM/I-derived ice motion with Arctic buoy data shows good agreement.

When using MODIS data to track color feature motion, the first step is to convert the chlorophyll-a concentration data to the same format and projection as SeaWiFS. In this case, MODIS and SeaWiFS images used are 1024 x 1024 pixels (with 1.1 km resolution), and then the Mexican-hat wavelet transform is applied to filter each image with several scales. Filtered images, 67 minutes apart, are then examined to find matching features using templates, which are then readily converted to motion vectors and block averaged onto a 17 km x 17 km grid. The accuracy of this technique is only limited by the persistence of the features and by the spatial resolution and navigational accuracy of satellite data. A feature displaced 1.1 km over 67 minutes will have a maximum uncertainty of 27 cm/s due to resolution. The geolocation uncertainty is about 100 m for MODIS, and is less than 1 km for SeaWiFS.

Figure 2 shows the mixed layer drift (red arrows) derived by wavelet analysis of feature tracking from MODIS and SeaWiFS chlorophyll-a concentration data (MODIS image as background) collected on May 8, 2000 separated by 67 minutes over the mid-North Atlantic Ocean. As shown in this figure, the Gulf Stream motion of 1.5 m/s and spin-off eddies have been well derived. Notice that the cold ring south of the Gulf Stream at the center bottom of the map is cyclonic, while the warm ring north of the Gulf Stream at the right center of the map is anti-cyclonic. The converging zone at Georges Bank is also clearly observed. The empty areas in the map indicate the regions where filtered features were not matched.

Comparison with drifter data

The field measurement of the water-following capability of the drifters, with vector-measuring current meters attached, were reported by Niiler et al. (1987). Several modeling studies provided a rational basis for the interpretation of the drifter measurements in the field. The accuracy of the water-following capability is dependent upon the winds and the drag area ratio. These drifters were designed to slip about 1 cm/s in 10 m/s winds, which is corrected for but still has 30% error. Location data provided by service Argos have a minimum error of 1 km for daily satellite average data and the error is about 1 cm/s. The total drifter error is leading to about 1.5 cm/s, which is much smaller than the uncertainty of satellite tracking results of 27 cm/s.

On May 8, 2000, data from four drifters were collected in the MODIS/SeaWiFS overlapped area (as compared to 790 vectors from the satellite data derived results). The drifter data are processed as daily averaged velocity vectors at noon and shown as dark arrows in Figure 2. A comparison of the satellite tracking results within the neighboring area of 17-km radius from drifter are shown in Table 1 for reference where speed in cm/s. The 17-km radius was chosen because of the data collection time difference (about 4 hours) and location errors induced by both drifters and satellite pixels. Notice that near the Gulf Stream the ocean color feature may drift as far as 22 km in 4 hours. In Table 1, the first drifter data has a speed of 14 cm/s, which is within the uncertainty of satellite tracking results and can not really be used for comparison. The second drifter has a speed of 24 cm/s and is only marginally useful for reference. The third drifter was probably moving in and out of Gulf Stream boundary, so its daily averaged speed is smaller than the satellite short-time (67 minutes) tracking results but both are in the same direction. The fourth drifter was also near the Gulf Stream boundary and its velocity (both speed and direction) is very consistent with two neighboring satellite-derived velocities in and out of the Gulf Stream. Although the drifter data are very limited, the comparison shows a general agreement between drifter data and satellite tracking results, especially for the cases near the Gulf Stream boundary.

Along the Gulf Stream just south of the MODIS/SeaWiFS overlapped area at Lat. 26.2°N and Lon. 79.6°W, drifter (#19463) data show a maximum daily averaged current of 1.51 m/s (Table 1). The mean current speed along the Gulf Stream in the overlapped area is found to be 1.59 m/s from the satellite data which is generally larger than daily averaged drifter data due to short-time tracking. These results indicate that satellite ocean color data can be used to derive mixed layer drift, to identify oceanic processes, and to improve our current knowledge of mixed layer drift and related processes.

Comparison of MODIS and SeaWiFS Data

Currently, to compare SeaWiFS and MODIS, one makes no correction for advection-induced change in time, just a simple pixel-pixel comparison. Advection between ocean color feature locations will add to the RMS errors, especially in high gradient regions. The satellite-derived current field can be used to assess the impact. Using the derived initial and end pixel numbers of the tracked features or the drift vector, one can then compare chlorophyll values at the original and moved locations.

Figure 3 shows the comparison of chlorophyll-a concentration data from MODIS and SeaWiFS (a) at the same locations, and (b) at the advected locations using the center pixel of a 17 km * 17 km box surrounding the vector location. The root-mean-square (RMS) difference of chlorophyll concentration between these versions of MODIS and SeaWiFS chlorophyll products are 1.0124 mg/m3 (or 0.1415 in log value) and 0.9701 mg/m^3 (or 0.1358 in log value) at the same locations and at the advected locations, respectively. The data points are more lined-up and focused after including the advection. A reduction of 4 % on RMS indicates the validity of mixed layer drift derived from satellites. If a simple regression is used to eliminate the bias, the reduction of RMS difference is increased to 6.3%. Most of the points of improvement are at the locations where SeaWiFS predicts higher chlorophyll than the preliminary MODIS algorithm used here. This implies that the low chlorophyll concentration areas near the Gulf Stream were moved into the relative high concentration locations. Although the improvement is not significant due to the bias between MODIS and SeaWiFS, the comparison demonstrates the drift field derived from satellite data is generally correct at the first order. This also indicates that the drift is generally in the tangential direction of concentration area, and is not across the high gradient regions. Once the advection effects are included, other nonlinear effects of biological growth/decay and diffusion processes can be further estimated in the future.

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Figure Caption

Fig. 1. Chlorophyll-a concentration data collected over US east coast from (a) MODIS, and (b) SeaWiFS on May 8, 2000 separated by 67 minutes.

Fig. 2. Mixed layer drift (red arrows) derived from MODIS and SeaWiFS chlorophyll-a concentration data over the mid-North Atlantic Ocean (MODIS image as background). The drifter data are shown as dark arrows.

Fig. 3. Comparison of chlorophyll-a concentration data from MODIS and SeaWiFS (a) at the same locations, and (b) at the advected locations.

Table 1. Comparison of velocity fields of the satellite tracking results and drifter data.

ID	Lon	Lat	Speed (Drifter)	Angle (Drifter)	Speed (Sat.)	Angle (Sat.)	Speed Diff.	Angle Diff.
15234	68.0	40.3	14.0	-165.6	37.6	76.0	-23.6	118.4
18809	64.2	40.1	23.6	-150.3	27.4	-90.0	-3.8	60.3
19465	74.1	36.3	40.7	37.3	98.7	56.3	-58.0	19.0
9635	65.0	38.8	85.6	-11.9	75.3	14.0	10.4	25.9
9635	65.0	38.8	85.6	-11.9	112.9	14.0	-27.2	25.9
19463	79.6	26.2	151.2	8.4				

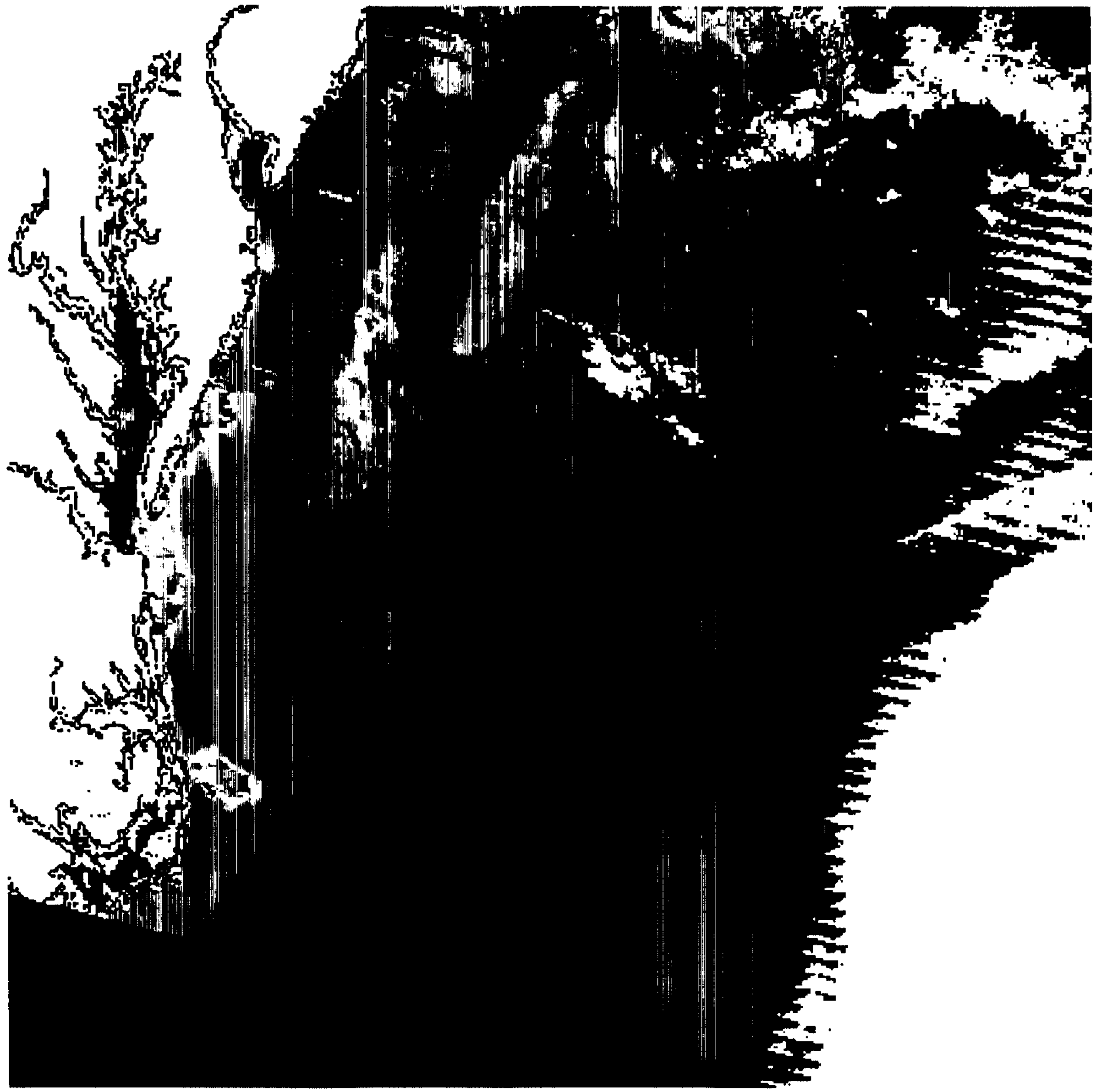


Fig. 1a

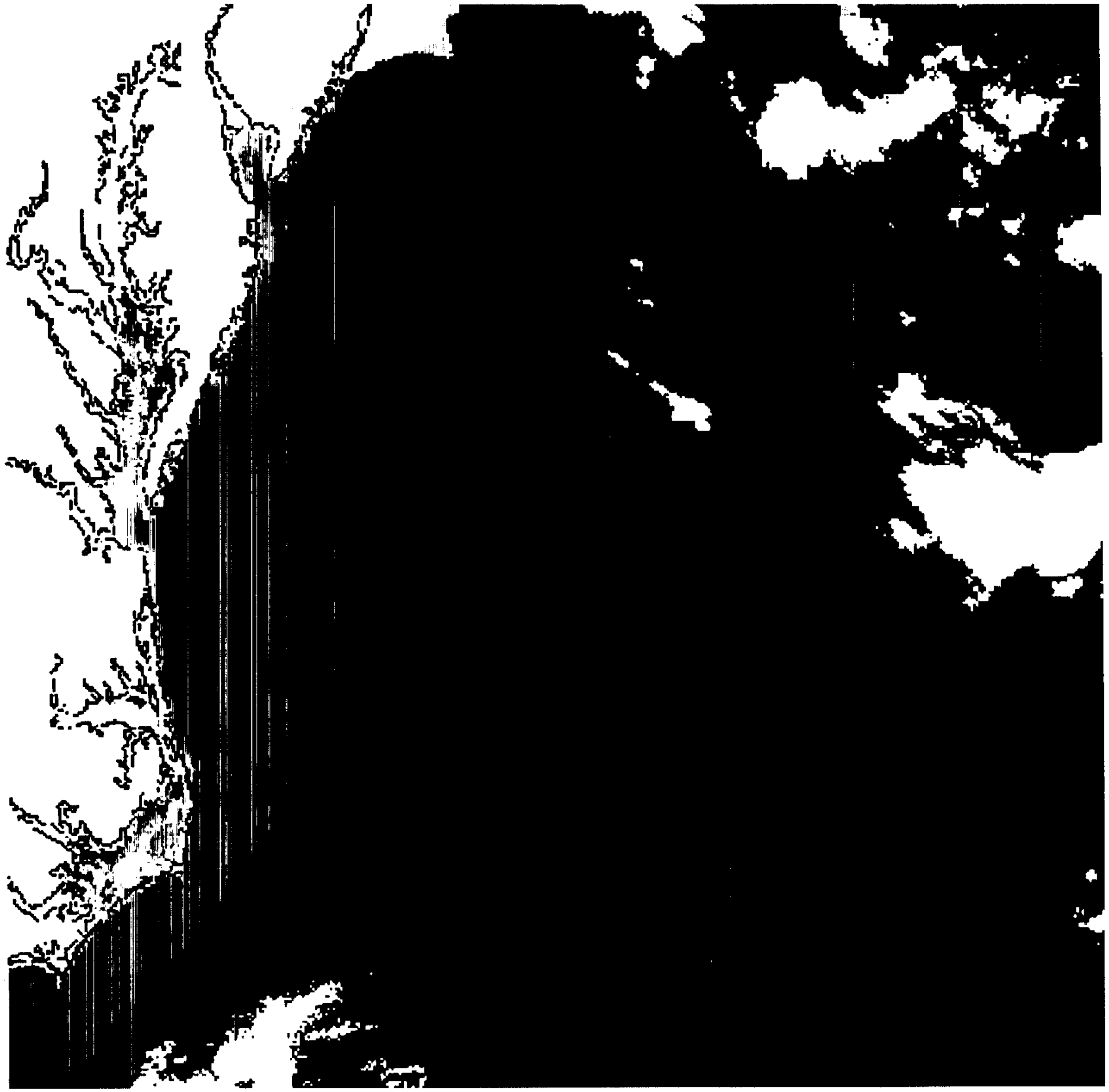


Fig. 1b

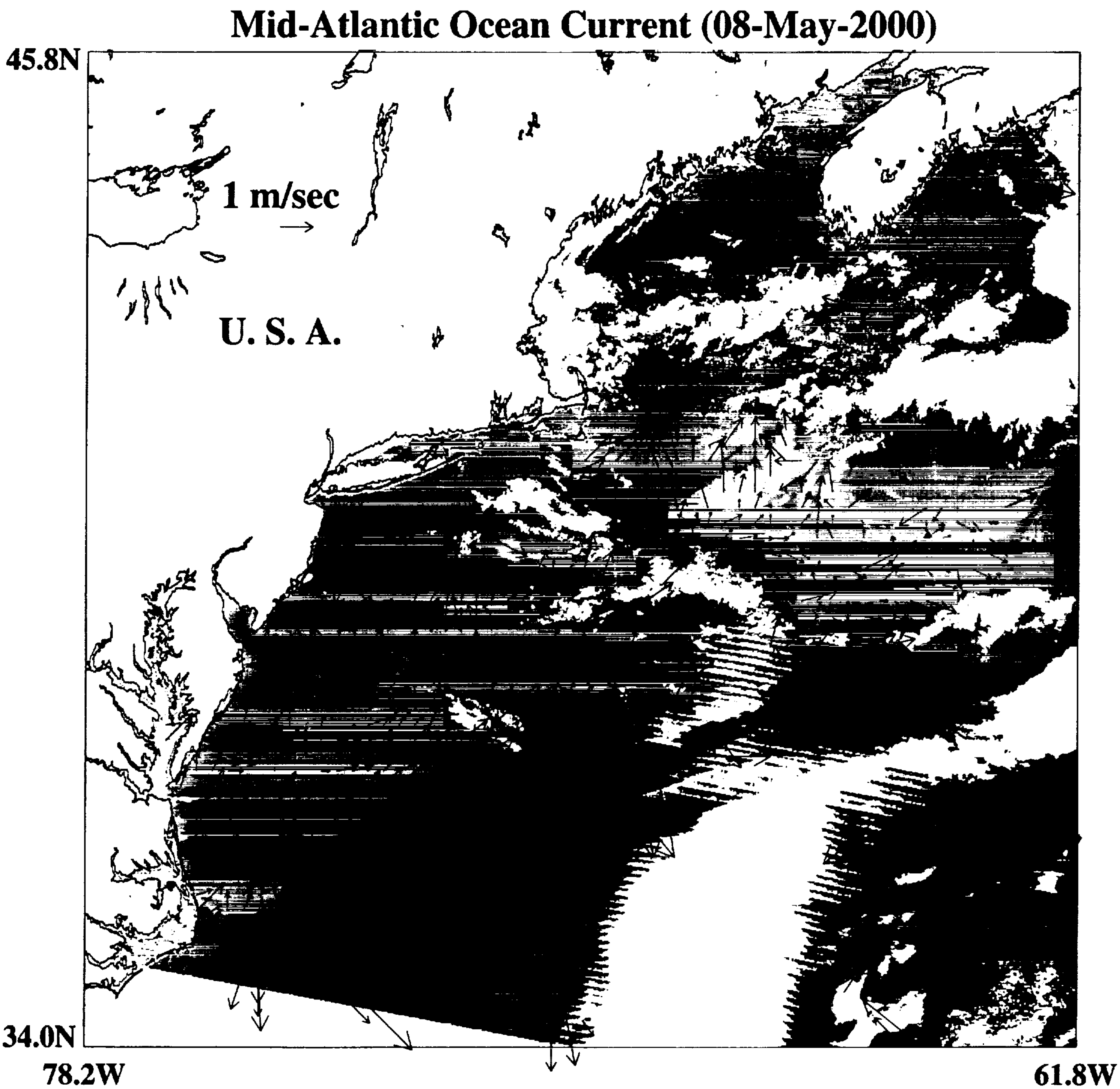
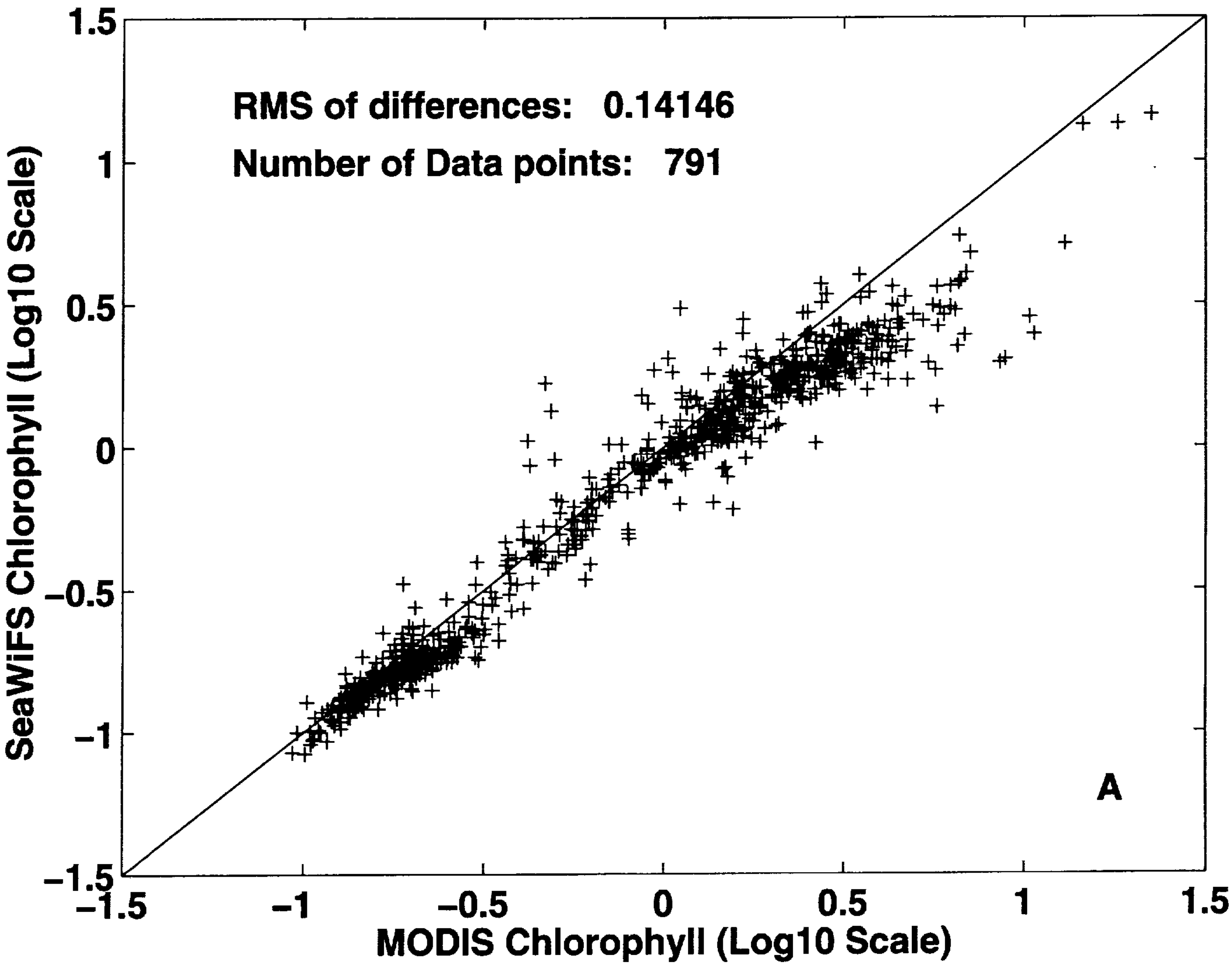

Mid-Atlantic Ocean Current (08-May-2000)
45.8N
34.0N
78.2W
61.8W
1 m/sec
U. S. A.

Fig. 2



RMS of differences: 0.14146
Number of Data points: 791
A
SeaWiFS Chlorophyll (Log10 Scale)
MODIS Chlorophyll (Log10 Scale)
1.5
1
0.5
0
−0.5
−1
−1.5
−1.5
−1
−0.5
0
0.5
1
1.5

Fig. 3a

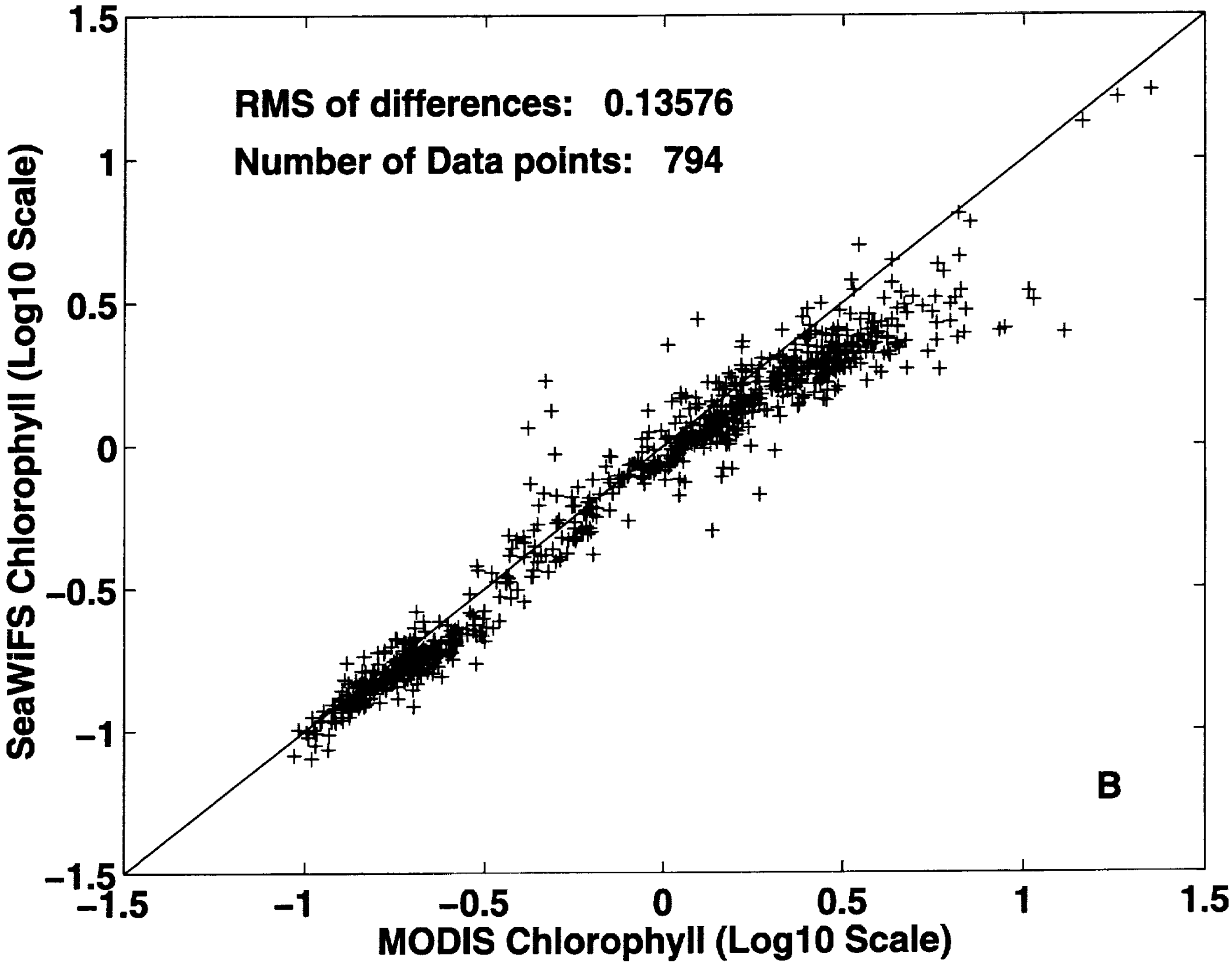

RMS of differences: 0.13576
Number of Data points: 794
B
SeaWiFS Chlorophyll (Log10 Scale)
MODIS Chlorophyll (Log10 Scale)
1.5
1
0.5
0
−0.5
−1
−1.5
−1.5
−1
−0.5
0
0.5
1
1.5

Fig. 3b